Cyclic Undrained DSS Testing of Christchurch Sandy Silty Soils

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1 Introduction

Earthquake-triggered soil liquefaction caused extensive damage and heavy economic losses in Christchurch during the 2010-2011 Canterbury earthquakes. The most severe manifestations of liquefaction were associated with the presence of natural deposits of clean sands and silty sands of fluvial origin. However:

- Liquefaction resistance of fines-containing sands is commonly inferred from empirical relationships based on clean sands (i.e. sands with less than 5% fines). Hence, existing evaluation methods have poor accuracy when applied to silty sands!
- Existing methods do not quantify appropriately the influence on liquefaction resistance of soil fabric and structure, which are unique to a specific depositional environment.

2 Scope of Research

To investigate and quantify the influence of fines content, soil *fabric* (i.e. arrangement of soil particles) and *structure* (e.g. layering, segregation) on the undrained cyclic behaviour and liquefaction resistance of fines-containing sandy soils from Christchurch using:

- A series of **Direct Simple Shear (DSS) tests** on soil specimens reconstituted in the laboratory with the **water sedimentation** technique.
- Comparison of DSS results against Triaxial tests already performed at the University of Canterbury on undisturbed (Gel-Push, Dames & Moore) and reconstituted (moist tamping) specimens of similar soils.

The poster summarizes observations on the effects of **fines content** and **specimen density** from selected DSS tests.

3 Direct Simple Shear (DSS) Test

Free-field response of level ground deposits under earthquake excitation is usually associated with simple shear mode of deformation of a soil element (Figure 1). The Direct Simple Shear (DSS) test was introduced in order to better approximate these loading conditions with respect to the triaxial test commonly used in geotechnical applications.

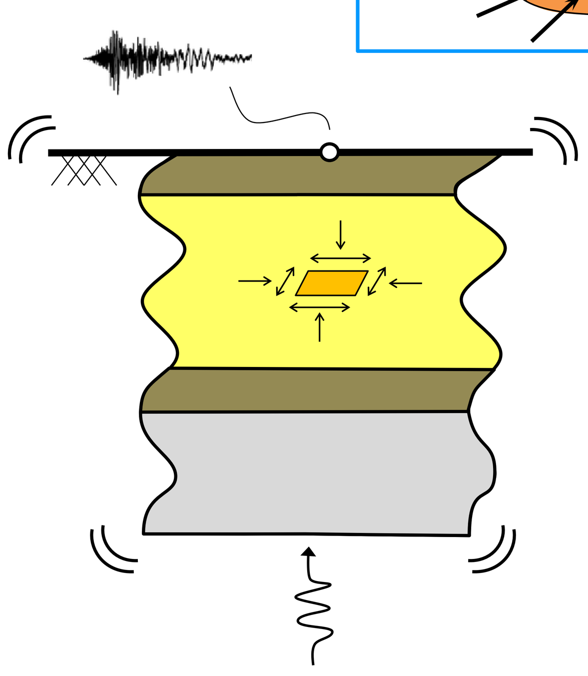

Figure 1. Propagation of SH seismic waves through level ground, free-field soil deposit.

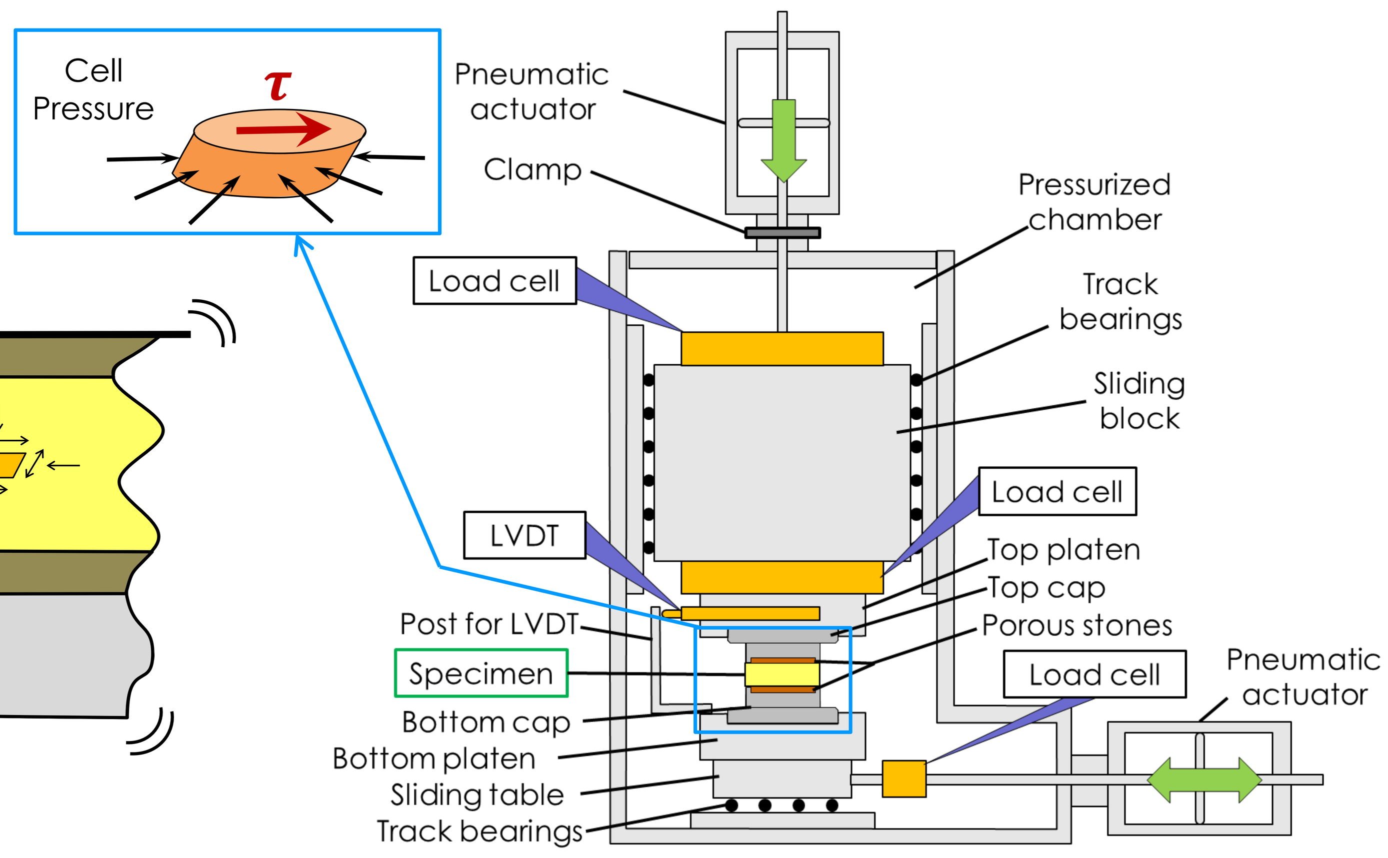

Figure 2. Cross-section of DSS device. *(modified after Boulanger, 1990)*

Laboratory tests are performed with a custom-built DSS device (Figure 2) with the following details:

- Specimen with circular cross-section wrapped within plain latex membrane (similarly to conventional triaxial testing devices).
- Lateral (cell) pressure applied through a confining chamber by means of compressed air.
- Back Pressure can be used for specimen saturation.

4 Water Sedimentation

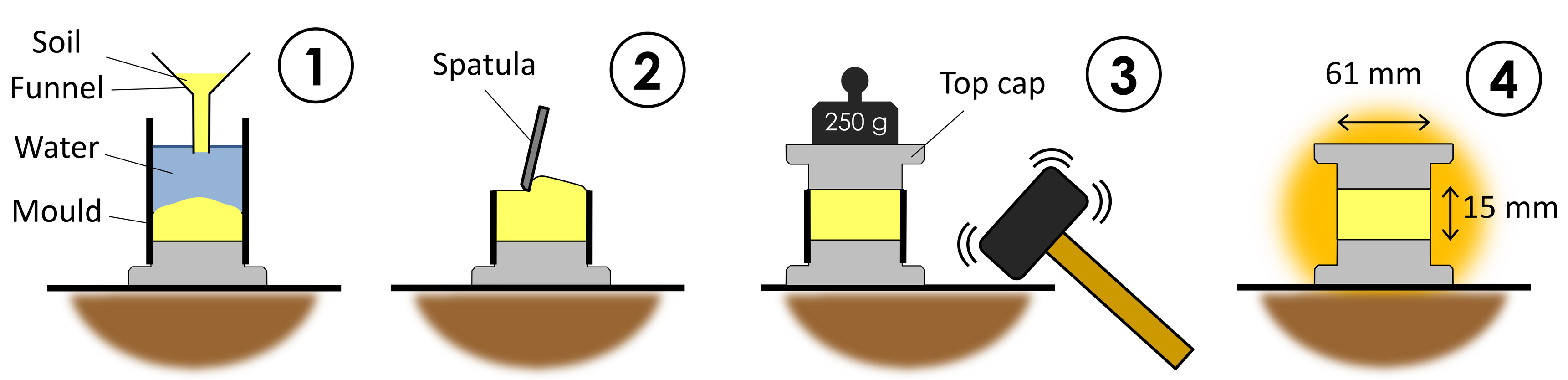

Figure 3. Water sedimentation technique for specimen preparation.

To obtain soil specimens with fabric and structure resembling those typical of fluvial soil deposits, which are common in Christchurch, specimens are prepared in the laboratory using the water sedimentation technique (Figure 3):

(1) Soil is poured in a mould filled with water using a funnel.
(2) After sedimentation, water in excess is drained through the specimen and removed from the mould. The top surface of the specimen is levelled before the top cap is positioned on the specimen.
(3) Higher densities (D_R>60% for RZ3 sand, >75% for RZ6 soils) can be achieved by using additional weights and the application of gentle vibrations on the table using a mallet.
(4) The procedure yields specimens of approximately 61 mm in diameter and 15 mm in height.

Pluviation can be performed either in a single stage or in multiple stages, so as to enforce either a segregated or a layered structure (Figure 4).

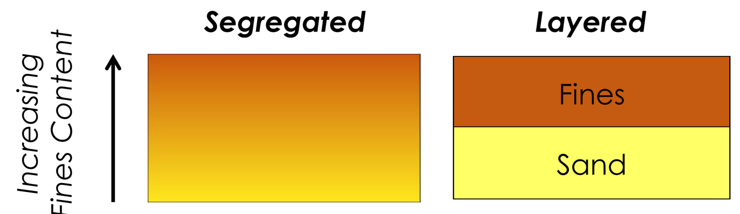

Figure 4. Examples of different soil structures.

Acknowledgements

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The DSS testing device employed in this study was designed and manufactured at the University of California, Berkeley, which kindly allowed permission for its use.

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5 Test Results

Test Soils: Tests are performed on two sands, a silt, and sand-silt mixtures of soils from Christchurch (Figure 5) with the following characteristics (Figures 6 and 7):

- **RZ3 sand:** Uniform sand with sub-angular grains and relatively clean surfaces, sampled at 5.7 m depth in the suburb of Avonside.
- **RZ6 soils:** Sand-silt mixtures obtained by recombining different fractions (>75 μm and <75 μm) of a fluvial silty sand with angular grains, sampled at 1.7 m depth in the suburb of Bexley.
- **RZ3-FC30 sand-silt:** A gap-graded mixture with FC = 30% obtained by combining RZ3 sand with RZ6-FC100 silt.

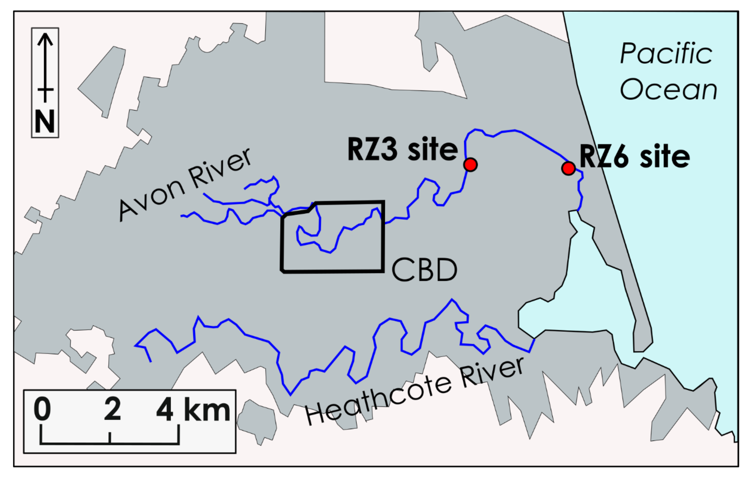

Figure 5. Location of sampling sites within the urban area of Christchurch.

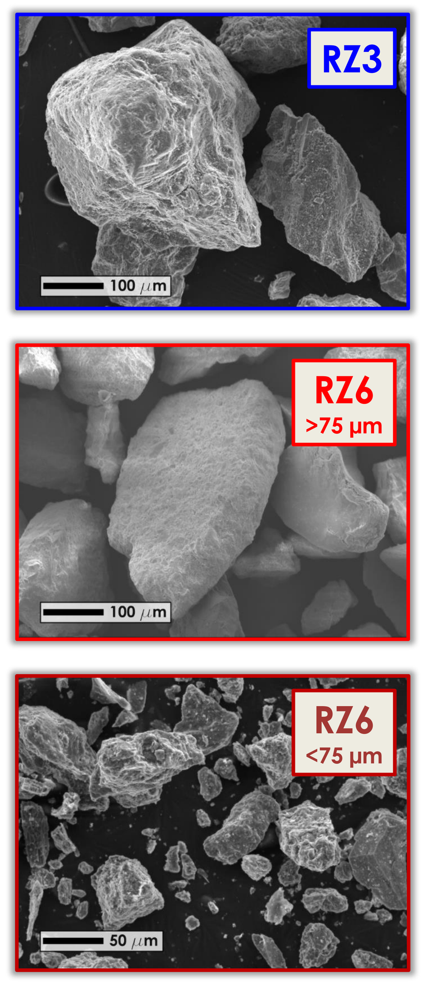

Figure 6. Scanning Electron Microscope images of test soils.

Soil	FC [%]	G_s	e_{min}	e_{max}	D_{50} [mm]
RZ3 sand	1	2.66	0.59	0.99	0.26
RZ6-FC9	9	2.66	0.69	1.19	0.12
RZ6-FC30	30	2.66	0.63	1.26	0.10
RZ6-FC53	53	2.69	0.60	1.24	0.071
RZ6-FC100	100	2.69	0.71	1.46	0.026
RZ3-FC30	30	2.67	0.46	0.91	0.20

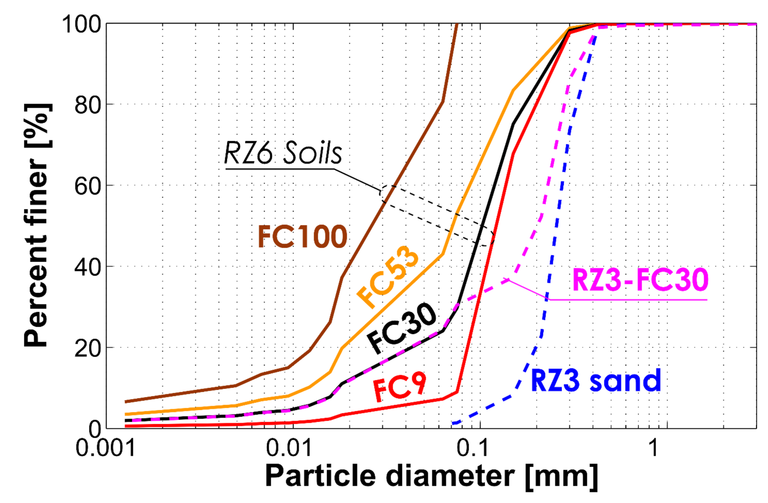

Figure 7. Particle size distributions and index properties of test soils.

Testing Procedure:

- Preparation of specimen at target relative density by water sedimentation.
- Saturation: percolate de-aired water (x5 spec. vol.) → apply Back Pressure (≥ 200 kPa).
- Consolidation to $\sigma'_V = 100$ kPa, $K = \sigma'_H/\sigma'_V = 0.5$. Post-consolidation B-value: 0.92-1.00.
- Closure of drainage valves (= undrained conditions).
- Stress-controlled cyclic shearing with uniform shear load of pre-defined amplitude and f = 0.05 Hz. Cyclic shearing takes place at constant height and constant $\sigma_H = \sigma_{cell}$.

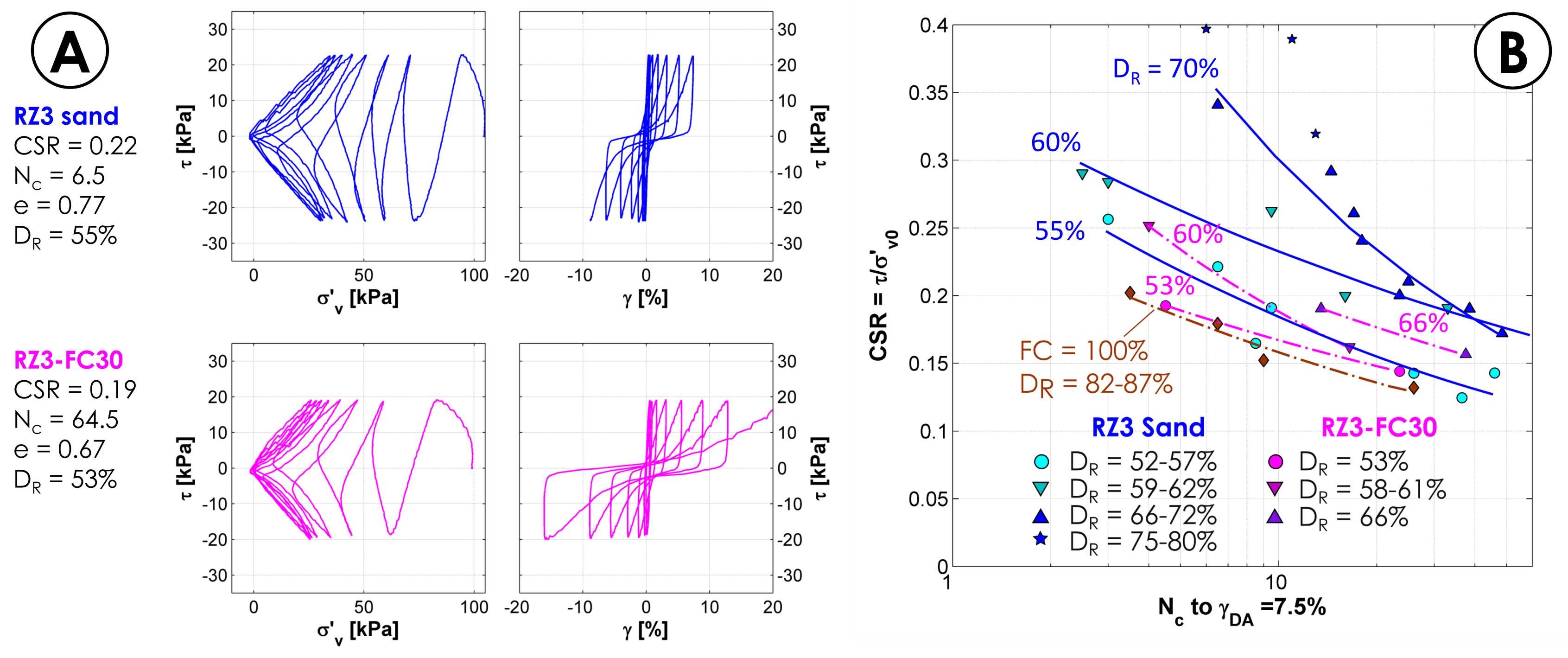

Figure 8. RZ3 sand and RZ3-FC30 sand-silt: (A) Stress paths and stress-strain response in cyclic DSS of specimens with similar D_R; (B) Number of cycles against CSR for γ = 7.5% DA in cyclic DSS.

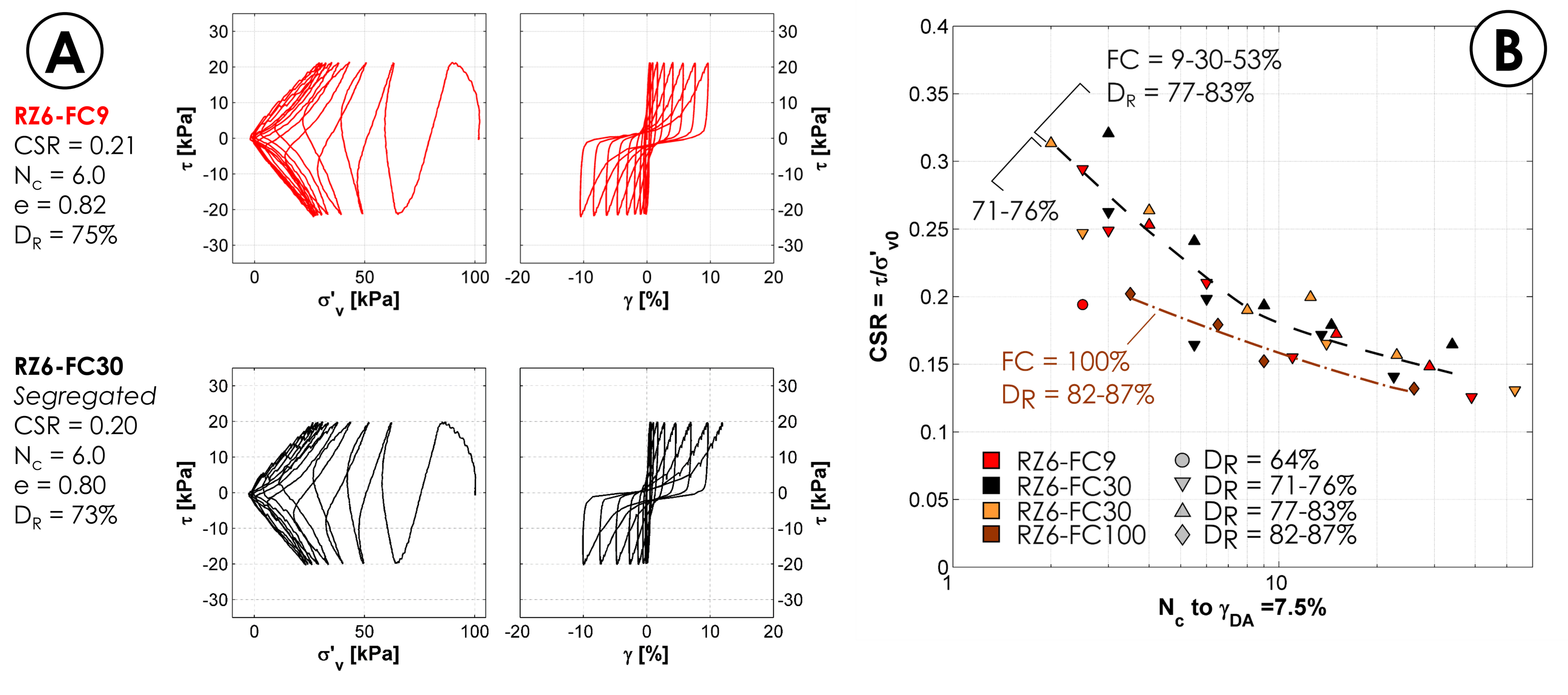

Figure 9: (A) Stress paths and stress-strain response of RZ6-FC9 and RZ6-FC30 sand-silt specimens tested in cyclic DSS tests at similar CSR; (B) Number of cycles against CSR for γ = 7.5% DA in cyclic DSS for RZ6 soils with different fines contents.

Observations from DSS Tests:

- All tested specimens attained a condition of initial liquefaction (r_u = 1.0), independently from host sand used in the preparation, fines content, or specimen density.
- RZ3 sand and RZ6-FC9, which are the host coarse-grained soils used in the preparation of sand-silt mixtures, show remarkably different liquefaction resistances at similar relative densities, with RZ3 sand having the greater liquefaction resistance. Changes in liquefaction resistance are consistent with changes in relative density during preparation: RZ3 sand exhibits a significant increase in liquefaction resistance, while this change is less significant in RZ6-FC9.
- The liquefaction resistance of RZ3 sand is significantly affected by the addition of fines (Figure 8). Specimens of RZ3-FC30 sand-silt mixture exhibit lower liquefaction resistance than RZ3 sand with similar relative density.
- For mixtures prepared with RZ6-FC9, the relationship between relative density and fines content (up to tested value of FC = 53%) appears independent from fines content.
- RZ6-FC100 silt has lower liquefaction resistance than other tested soils despite its higher D_R